The Hatfield model, sponsored by AT&T and MCI, should not be used as a basis for determining TS/TELRIC or TELRIC (TS/TELRIC) for 3 reasons: (1) It fails internal consistency tests required of valid cost models, consequently it is not a valid cost model and cannot represent the minimum cost of producing outputs using the best forward looking technology; (2) it has never been empirically validated, e.g. by comparing the results it produces to those generated by the real world phenomena it purports to model; and (3) it is based both conceptually and empirically on a static notion of costs that is totally inappropriate in this context.

The consequences of these errors are such that they render the Hatfield model useless for estimating TS/TELRICs. Because the Hatfield model is internally inconsistent, it will produce TS/TELRIC that are biased in a direction that can be determined only by comparing its results to the results of a correctly performed cost analysis. In those few instances where the Hatfield results can be compared to actual data, it produces results that are significantly lower than the actual. Because it has never been subject to empirical testing one would routinely expect of a cost model, there is a guide to neither the extent nor the importance of any other biases. No Commission would accept a demand forecast that was not based on real numbers. Nor would it accept a model that was not empirically validated. Finally, the fact that the Hatfield approach is a static rather than a dynamic one produces fill factors that are too high, costs of capital that are too low and depreciation rates that are too slow. Indeed, by ignoring dynamics altogether, it fails to be forward looking even in concept. In consequence of all of this, the Hatfield model is totally useless as an estimator of TS/TELRIC and has no place in a debate on pricing.

(1) THE HATFIELD MODEL IS NOT A VALID COST MODEL:

The Hatfield model is not a valid economic cost model because it fails the internal and external consistency checks required of any cost model. This is more than just a theoretical point. Failure to satisfy these checks means that the Hatfield cannot represent the minimum cost of producing outputs using the best forward looking technology. In Attachment I, I show this and also show that any numbers the Hatfield model produces purporting to be TS/TELRICs are biased in an unknown direction. This makes them useless for even the minimal task of providing upper and or lower bounds. Further, I will show that the underlying approach is so flawed as to render the Hatfield model impossible to fix without a complete overhaul, starting with the basic conceptual approach and ending with data requirements.

Cost models and TS/TELRIC calculations:

The primary purpose of a cost model is to answer the question "What is the minimum cost of producing a stream of outputs using the best forward looking technology and facing a perhaps uncertain stream of input prices?" To use a cost model to calculate a TS/TELRIC for a product, one calculates the minimum cost of doing business as usual and subtracts from that the minimum cost of doing business if a product line were dropped from production. Both components of this difference should be dynamic cost functions, not costs calculated only for the year in question, but costs calculated over the optimal planning horizon of the firm. Single period static cost functions are totally inappropriate.

Valid cost models:

A valid cost model shows the relationship between the minimum cost of producing a flow of services using the most efficient technology, given a set of expected input prices, starting today and flowing into the future as far as the firm's optimal planning horizon. Specifically, for input prices and output levels in each year of the planning period, it shows the minimum present discounted value of producing those levels of outputs.

As a consequence of this minimization, costs functions and cost models necessarily satisfy a set of mathematical properties which can be found in a first year graduate textbook such as 'Microeconomic Analysis' by Hal Varian. Rather than a complete listing of them, I will discuss two that the Hatfield model clearly violates. The first is linear homogeneity in prices; this means if all prices are increased proportionately, then total costs will increase by the same proportion. The second is the derivative property. An easily understood form of the derivative property is this: the percentage increase in total costs as a consequence of a one percent increase in the price of an input, i.e., labor , loops, wire, and the like, will be exactly equal to the share of total costs directly attributable to that input. So if cable of a certain grade comprises 10% of total costs and its price rises 1%, then total costs should rise 10% as a consequence.

The Hatfield Model Fails on Theoretical Grounds:

Any function or cost model that fails even one of the criteria required of a cost function, whether as stated above or found in a text, cannot represent the minimum cost of producing services using the best forward looking technology. Nor can it be made to do so; it is a mathematical impossibility. In the Appendix, I show formally that the Hatfield Model violates the derivative property and so cannot represent a cost function. Whereas, the percentage increase in the minimum production costs as a consequence of a one percent change in the price of an input, i.e., labor , loops, wire, and the like, should be exactly equal to the share of total costs directly attributable to that input, in the Hatfield model that percentage will be larger by a fraction equal to the expense and installation factors applied to the cable expenditure. So, if cable of a certain grade comprises 10% of total costs and installation comprised 10% of costs, and the price of cable price rises 1%, then the Hatfield model would predict costs will rise 20% rather than the 10% required of a valid cost model. Thus, an internal check on the validity of the Hatfield model would be to check if increasing the price of any input by 1% would just increase the costs by a fraction equal to the cost share of that input. The result in the appendix shows that, due to the approach taken by the authors of the Hatfield model it is theoretically impossible for the Hatfield model to satisfy this most basic of all cost function criteria.[1]

As might be expected, using an invalid model to predict costs or components of costs will give anomalous results. I give a theoretical account of the biases they cause in the appendix. The upshot is that the bias can only be determined by doing a correct cost study and comparing the correct results with the biased Hatfield results. In his paper, which I have included as an attachment, Dr. Tardiff examines one occasion of that bias, that of installation costs. Specifically, the Hatfield model underestimates TS/TELRICs by half.

(2) THE HATFIELD MODEL HAS NOT BEEN EMPIRICALLY VALIDATED:

Theory aside, the Hatfield Model also fails on methodological grounds. The model does not seem to have been run through the set of theoretical and empirical tests that are routinely used to ferret out modeling errors. As a consequence, it is impossible to determine the extent to which any additional biases might exist and whether they are important empirically. A cost model is typically validated in two

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1 The multiplicative structure of cost factors which give the Hatfield model this property is, in part, borrowed from BCM I. However, the authors of BCM I understood the implications of the structure they chose. For them, in order to "run" BCM I for a different set of input values (such as cable costs) it would be necessary to recalibrate factors in the model, such as those dealing with installation and structure costs. Hatfield has ignored this fundamental premise of BCM I – indeed, they have exploited this weakness of the model by changing inputs to which the model is particularly sensitive, without making the necessary changes in other factors. The BCM II model has adopted a different structure which reduces its reliance on multiplicative factors.

ways. First, it is checked to see if it satisfies the cost minimization criteria referred to above. Second, the model is run to produce costs for a set of benchmark scenarios with known costs. Then the predictions from the model are compared to the known actual costs. The process is similar to the kind of backcasting exercise most Commissions would require of a demand forecasting model before approving the use of its results. A model whose results match the benchmark results closely is considered valid. For example, if a cost model is calibrated or estimated using the data from a specific firm over a certain time period then, at the very least, the model should be able to reproduce the data from which it was constructed.

Failing the theoretical set of tests is not fatal in itself. Even when cost models fail the first set of tests, researchers will often use them if they pass the second set on the grounds that models need only be close, not exact. For some purposes this may be permissible although I would not personally recommend such an approach. For the purpose of estimating TS/TELRIC, it is an approach few would recommend. The scenarios to be compared involve large and purely hypothetical changes to the inputs or outputs relative to the benchmark since calculating a TS/TELRIC involves the difference between business as usual minimum costs and a hypothetical minimum cost when a whole production process or service is dropped. Currently we have little or no information on how a firm operating under such circumstances, e.g., without any residential lines, would be engineered.

The Hatfield authors do not present the results of the battery of tests professional economists would expect cost functions to be put through before publication and use. As the report of such tests is a common feature of reports on cost models, one must conclude the authors neither performed such standard tests nor knew that professional practice required them. My discussions with various sponsors of the Hatfield model have confirmed that no such tests have been performed. In addition, the model has not been peer reviewed to my knowledge. Consequently, we lack any independent verification of the model or its results

Although the Hatfield model has not been thoroughly empirically tested, it clearly violates at least some of the criteria required for a valid cost model. As I mentioned above, Dr. Tardiff has discovered that the Hatfield model produces a curious anomaly: doubling the price of cable results in a near doubling of the cost of installation. This phenomenon violates the linear homogeneity requirement mentioned above, unless installation and cable are strong substitutes for each other---which is unlikely. To understand why this violates linear homogeneity consider this. Under the Hatfield model if one doubles only the cable price, that by itself doubles both the cable cost and the installation cost. If, in addition, one also doubles the installation prices, then only two things can happen. Either there would be no effect due to the second price change, (i.e., costs would be unchanged) or costs will increase. If there is an additional effect, then linear homogeneity is violated, because doubling both prices more than doubled costs.[2] If there is no additional effect, that means the inputs used in installation decrease at a rate exactly necessary to offset their increased price so as to keep the expense constant. This can only be the case if cable and installation are substitutes. However, my understanding of installation is that cable and installation

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[2] Recall that doubling the first price already doubled costs.

are complements not substitutes so not much substitution is possible. In fact, so little substitution is possible that one should expect that doubling installation prices should double installation costs.

Other tests could and should be run. For example, one could run a large number of simulations where all input prices and outputs were varied and costs were predicted. Then these pseudo-data could be analyzed econometrically using common and well known techniques to see if the model gave results that conformed to those demanded by theory. If not, the model is refuted. If the model passes the internal consistency test, then it should be tested against real data in a variety of contexts and modified until it fits well.

The Hatfield Model Cannot Be Fixed:

The evidence above should be enough to convince even the most dedicated proponent that the Hatfield model is simply not ready for the work of guiding pricing. Unfortunately, the Hatfield model cannot be fixed to produce the correct TS/TELRICs. First, the multiplicative structure of the Hatfield model based on expenditure levels rather than unit levels is totally at odds with valid costing principles. Only where prices were stable both across firms and over time might such a shortcut be valid. To know one would need to run the empirical validity tests discussed above. Theoretically, the multiplicative structure is at the root of its failure to be a valid model, while using historical expense factors makes it backward rather than forward looking. I hasten to say here that this should not be taken to imply that historical data cannot be used. It can and should be but not in the crude summary form employed by Hatfield. For example an expense factor could be estimated as a function of lines, minutes of use, input prices and technology indicators. Then by forecasting the likely prices, lines, minutes of use etc., the expense factor could be made to be forward-looking. But even then the final test of the model must be whether or not it predicts reality well.

Second, it is an add-on to the first release of the Benchmark Cost Model, which was a model that was built for a completely different purpose, that of determining the costs of providing Universal Service at a location specific (Census Block Group) level. As a consequence the BCM structure is at variance with Hatfield's intended use, that of determining changes in costs from dropping whole lines of service in all locations. Moreover, whereas flaws in the BCM have been discovered and repaired, it is my understanding that the Hatfield authors have stated that they do not intend to redo their model in light of the corrections made in the second release of the BCM.

Fourth, Hatfield concocts estimates for business and second residential line. Although Hatfield attempts to legitimize the use of an ad hoc procedure by employing a vaguely described iterative procedure(as though using a mathematical sounding word makes inventing numbers valid), the procedure will not change the fact that there are an infinity of solutions to the problem posed by not having disaggregate business and second lines at the CBG level. Indeed, picking any one of them is no better or worse than picking another because they are all without substance. This brings me to my final point.

Finally, because it is a static rather than a dynamic model, it mishandles growth and underestimates the true forward-looking cost of capital. First, in ignoring growth, it mischaracterizes, as inefficient over-capacity, that spare capacity which results from optimal timing of laying discrete plant. Hatfield's insistence that fill factors are too low is a case of this mischaracterization. At least since the mid 1970's it has been well known that in a dynamic context, the problem of optimally investing in discrete plant when there is growth has a component not found in static situations. In his 1978 paper in the *Review of Economic Studies*, David Starret shows that the cost minimizing firm in a dynamic situation trades off some spare capacity against the economies of scale in construction. The firm cost minimizes by choosing the lengths of the intervals between which it invests. During periods between investments there will always be spare capacity and it is often optimal and cost minimizing to always have spare capacity. Moreover, the mathematical structures that might be appropriate in a static situation may not be in the dynamic one. To determine whether or not they are appropriate requires the kind of empirical testing that the Hatfield model has not undergone.[3]

Second, it underestimates real cost of capital by ignoring the effects on the cost of capital that attend (a) the increased riskiness of an industry moving hurriedly into competition and (b) the increased economic depreciation rates required recover investment in current plant and equipment. Failure to recover sunk investment has severe economic consequences; for the rate and level of the recovery of capital not only tell firms which activities to direct the use of their existing equipment but also

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3 As a side note I find it discouraging that real cost data from real firms are being compared to the results of the Hatfield model, (of course not in a formal testing sense), and when the firm data are found to differ from the Hatfield predictions, the sponsors of the model claim that is evidence that the firms are inefficient. If anything it provides evidence that the Hatfield model is simply wrong.

dictate whether or not there is an incentive to replace equipment, as it becomes obsolescent, with the next generation. Indeed, by ignoring dynamics altogether, it fails to be forward looking even in concept. Dr. Jerry Hausman makes some of these same points in his reply affidavit in Docket 96-98 before this Commission. Consequently, the Hatfield model is totally useless as an estimator of TSLRIC or TELRIC and has no place in a debate on pricing.[4]

In the end the Hatfield simply has too many errors both conceptual and empirical, and has had too little verification to have any role in the current debate. Indeed, it is my understanding that in the Universal Service debate in California, the California Public Utilities Commission has come to the same conclusion and has rejected the Hatfield model in favor of a different approach.

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4 Dr. Timothy Tardiff has written a critique of Hatfield concerning errors in measuring the cost of capital, fill factors, and whether it is valid to assume that all volumes currently served by local exchange carriers will be served by a brand new entrant that instantly materializes. While serious, each can be dealt with within Hatfield model by a change to the inputs. My criticism is more fundamental; it deals with problems that cannot be fixed within the context of the model.

Attachment I:

In this Attachment I demonstrate that the Hatfield Model violates the derivative property and that it produces biased TS/TELRICs.

Let i=1,...,n index the types of cable, let p_{ci} be the price per foot of the ith type of cable, let L_{ci} be the miles of the ith type of cable, let E_{si}^{o} be the base year expense of structure and installation for cable of type i and let E_{ci}^{o} be the base year expense of cable of type i, let E_{si} be the cost minimizing expenditure on structure and installation for cable of type i and let E_{ci} be the cost minimizing expenditure on cable of type i, and let y be the output for which a TS/TELRIC is desired.

The Hatfield Model Violates the Derivative Property:

The loop cost part of the Hatfield model may be represented as

$$C = \sum_{i=1}^{n} \left(p_{ci} L_{ci}\right) \left[1 + \left(\frac{E_{si}^{o}}{E_{ci}^{o}}\right)\right].$$

The derivative property of cost functions requires that the derivative of a cost function with respect to an input price give the optimal amount of the input.[1] Thus, the derivative of C with respect to p_{ci} should give L_{ci}. Symbolically this is,

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1 I use the level form of the derivative property here rather than the proportional or logarithmic derivative form I used in the text, because the level form has easier mathematics.

$$\frac{\partial C}{\partial p_{ci}} = L_{ci}\,.$$

Unfortunately, direct calculation of the partial derivative of the Hatfield model yields

$$\frac{\partial C}{\partial p_{ci}} = L_{ci}\left[1 + \left(\frac{E^{o}_{si}}{E^{o}_{ci}}\right)\right]$$

which is an over statement of L_{ci} by a factor of

$$\left[1 + \left(\frac{E^{o}_{si}}{E^{o}_{ci}}\right)\right].$$

Hatfield TS/TELRICs are biased.

For simplicity, assume only expenditures on cable and installation and structure. The results are exactly the same with switching and expenses except the notation is more elaborate and difficult to follow. The Hatfield Model gives a cost function of the following form:

$$C^* = \sum_{i=1}^{n} (p_{ci} L_{ci}) \left[1 + \left(\frac{E_{si}^o}{E_{ci}^o}\right)\right]$$
$$= \sum_{i=1}^{n} (E_{ci}) \left[1 + \left(\frac{E_{si}^o}{E_{ci}^o}\right)\right].$$

The cost minimizing cost function is

$$C = \sum_{i=1}^{n} (E_{ci} + E_{si}).$$

Use the difference calculus to obtain Hatfield TS/TELRIC and the true TS/TELRIC. For the Hatfield Model,

$$\Delta C^* = \sum_{i=1}^{n} (\Delta E_{ci}) \left[1 + \left(\frac{E_{si}^o}{E_{ci}^o}\right)\right],$$

for the true model

$$\Delta C = \sum_{i=1}^{n} (\Delta E_{ci} + \Delta E_{si}).$$

Taking the difference between the terms gives

$$\Delta C - \Delta C^* = \sum_{i=1}^{n}\left(\Delta E_{ci} + \Delta E_{si} - (\Delta E_{ci})\left[1 + \left(\frac{E_{si}^{o}}{E_{ci}^{o}}\right)\right]\right)$$
$$= \sum_{i=1}^{n}\left(\Delta E_{si} - (\Delta E_{ci})\left(\frac{E_{si}^{o}}{E_{ci}^{o}}\right)\right)$$
$$= \sum_{i=1}^{n} E_{si}^{o}\left(\frac{\Delta E_{si}}{E_{si}^{o}} - \frac{\Delta E_{ci}}{E_{ci}^{o}}\right).$$

Dividing by Δy, multiplying and dividing by y and rearranging terms gives

$$\frac{\Delta C - \Delta C^*}{\Delta y} = \sum_{i=1}^{n}\frac{E_{si}^{o}}{y}\left(\frac{\Delta E_{si}}{E_{si}^{o}}\frac{y}{\Delta y} - \frac{\Delta E_{ci}}{E_{ci}^{o}}\frac{y}{\Delta y}\right)$$

which is the bias in the incremental costs. The bias is then a weighted sum of the differences between installation and structure expenditure elasticities and the cable expenditure elasticities.

References:

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Certificate of Service

I, Ann D. Berkowitz, hereby certify that copies of the foregoing "GTE's Comments on Cost Models" have been mailed by first class United States mail, postage prepaid, on August 9, 1996 to all parties of record and the Federal-State Joint Board.

Ann D. Berkowitz